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[54] THERMAL DETECTOR WITH NUCLEATION ELEMENT AND METHOD

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[51] Int. Cl.⁶ **G01K 7/00**

[52] U.S. Cl. **250/338.3**

[58] Field of Search 250/338.3

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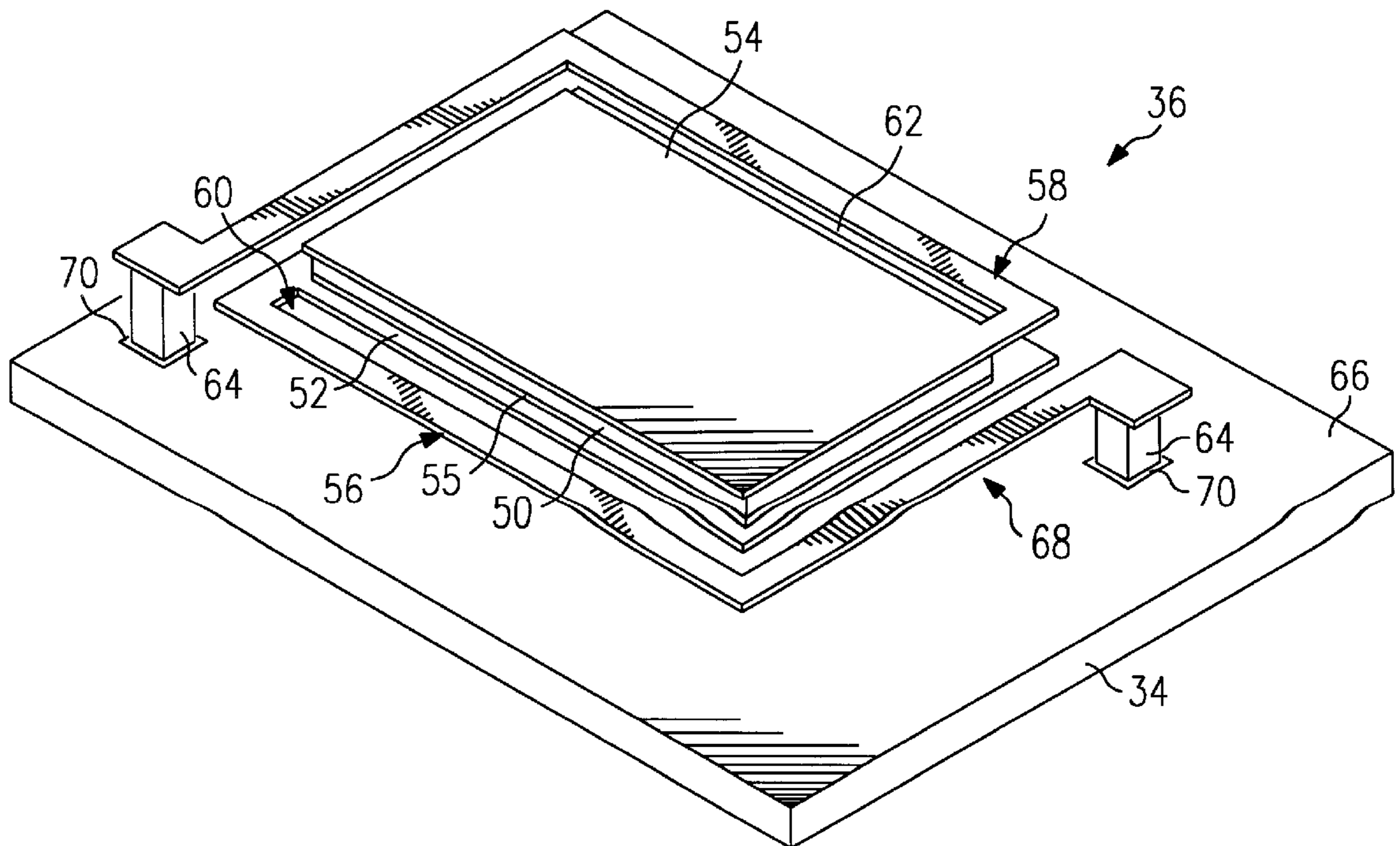
Primary Examiner—Constantine Hannaher

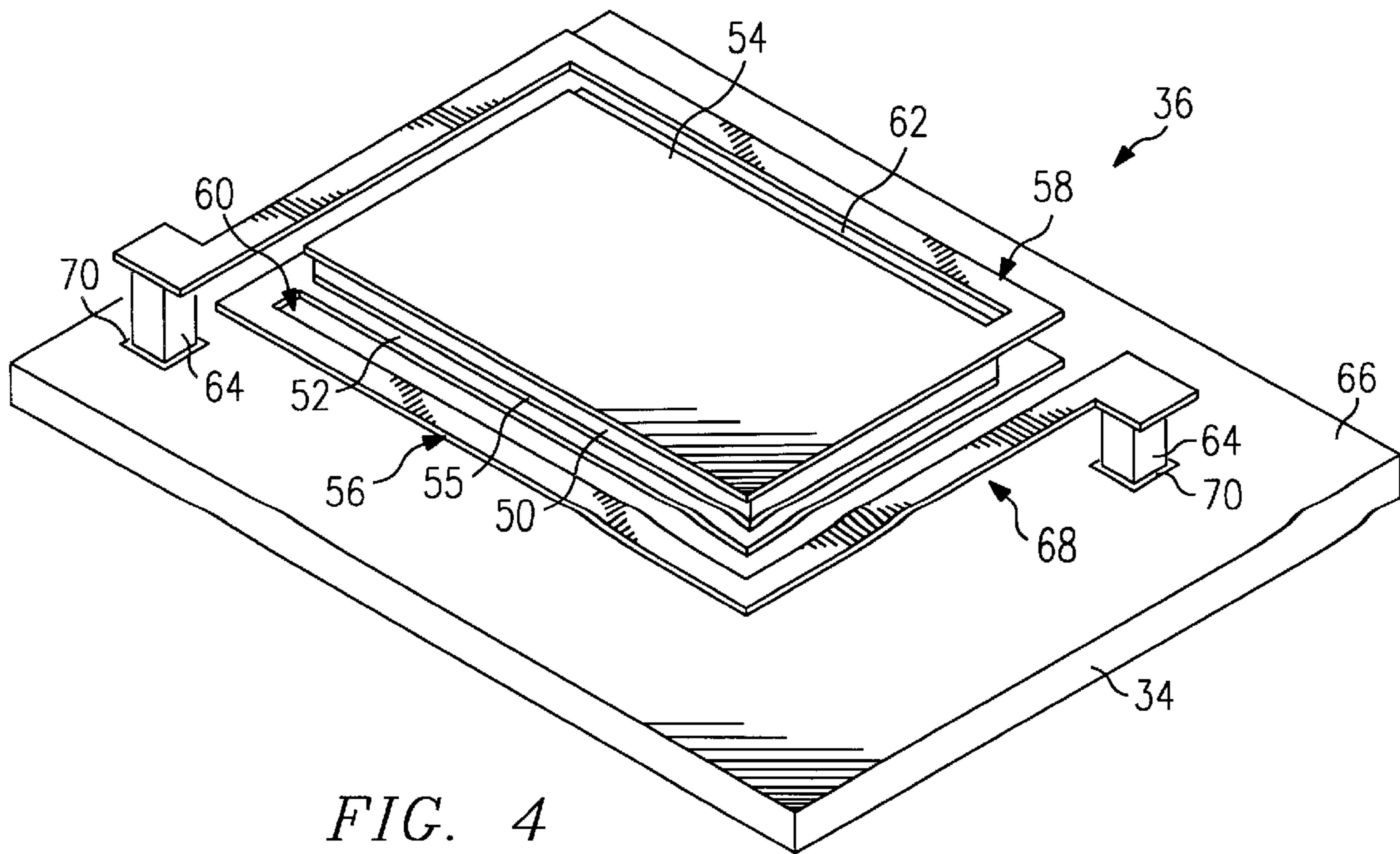
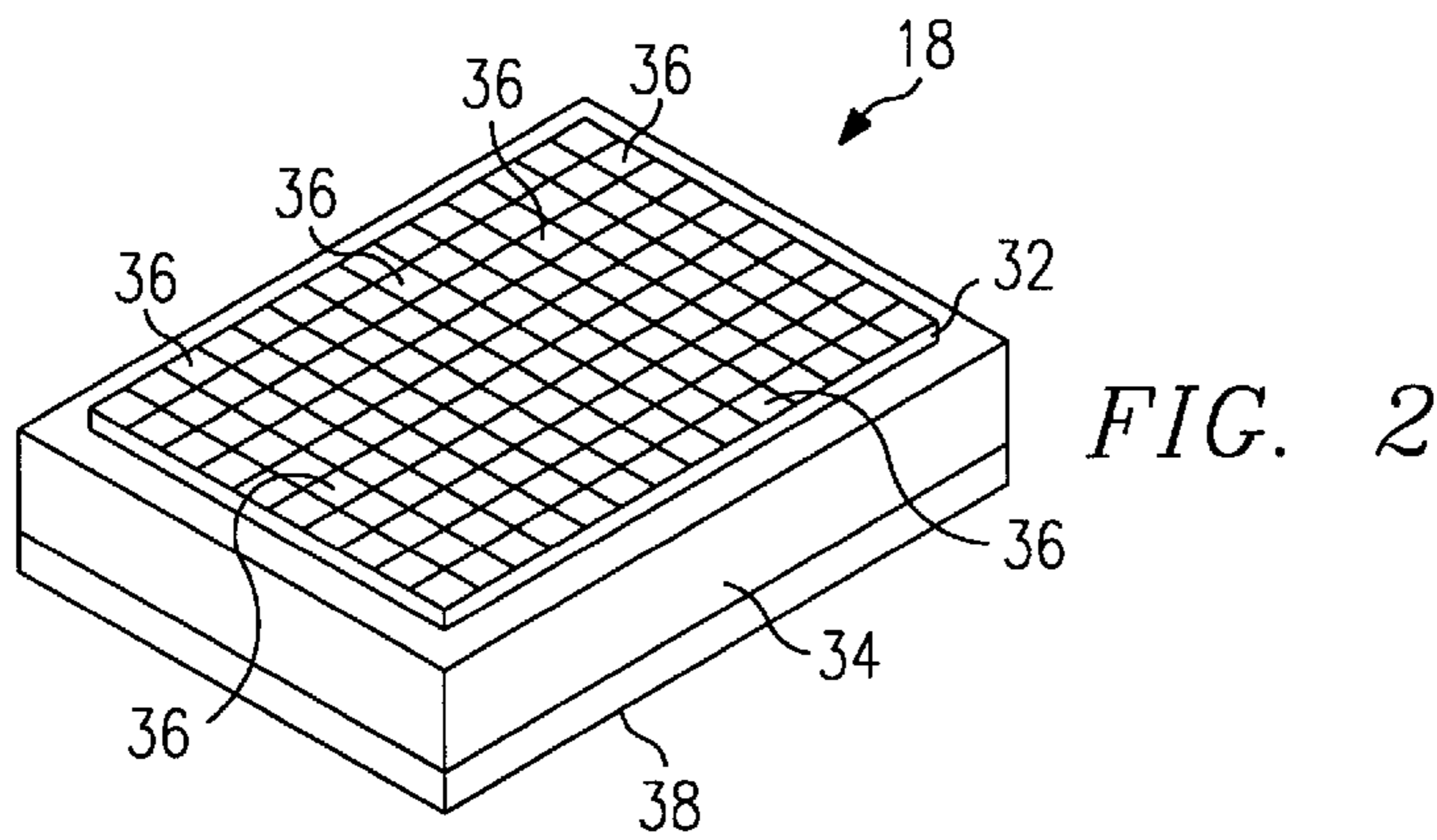
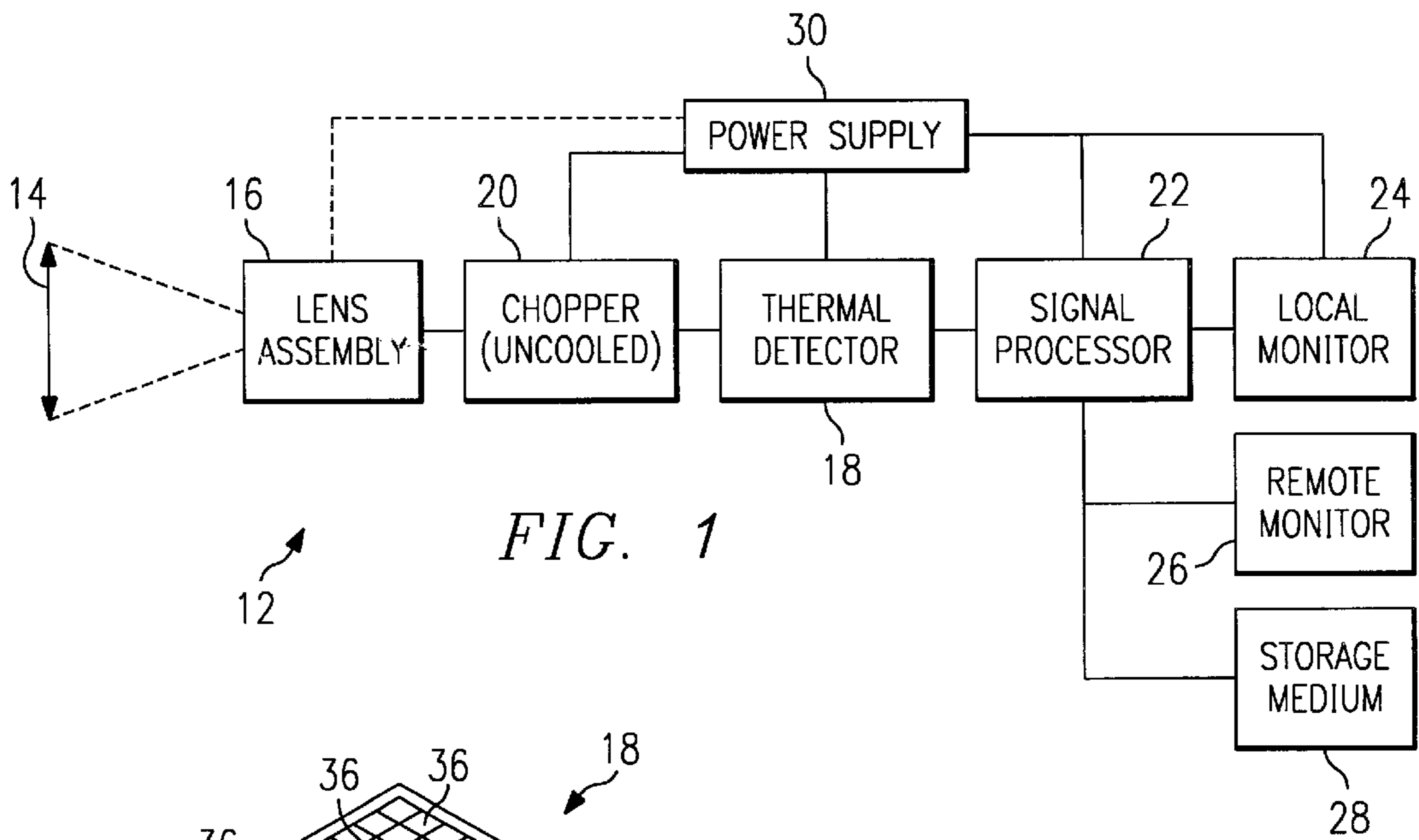
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[57] ABSTRACT

Thermal sensor (36) mounted to a substrate (34). The thermal sensor may include a first thin film electrode (52), a nucleation element (55), a thermally sensitive element (50) and a second thin film electrode (54). The first thin film electrode (52) may be disposed adjacent to the nucleation element (52). The thermally sensitive element (50) may be in electrical communication with the first thin film electrode (52). The thermally sensitive element (50) may comprise a plurality of preferentially-ordered crystals. The second thin film electrode (54) may be in electrical communication with the thermally sensitive element (50) opposite the nucleation element (55).

23 Claims, 3 Drawing Sheets





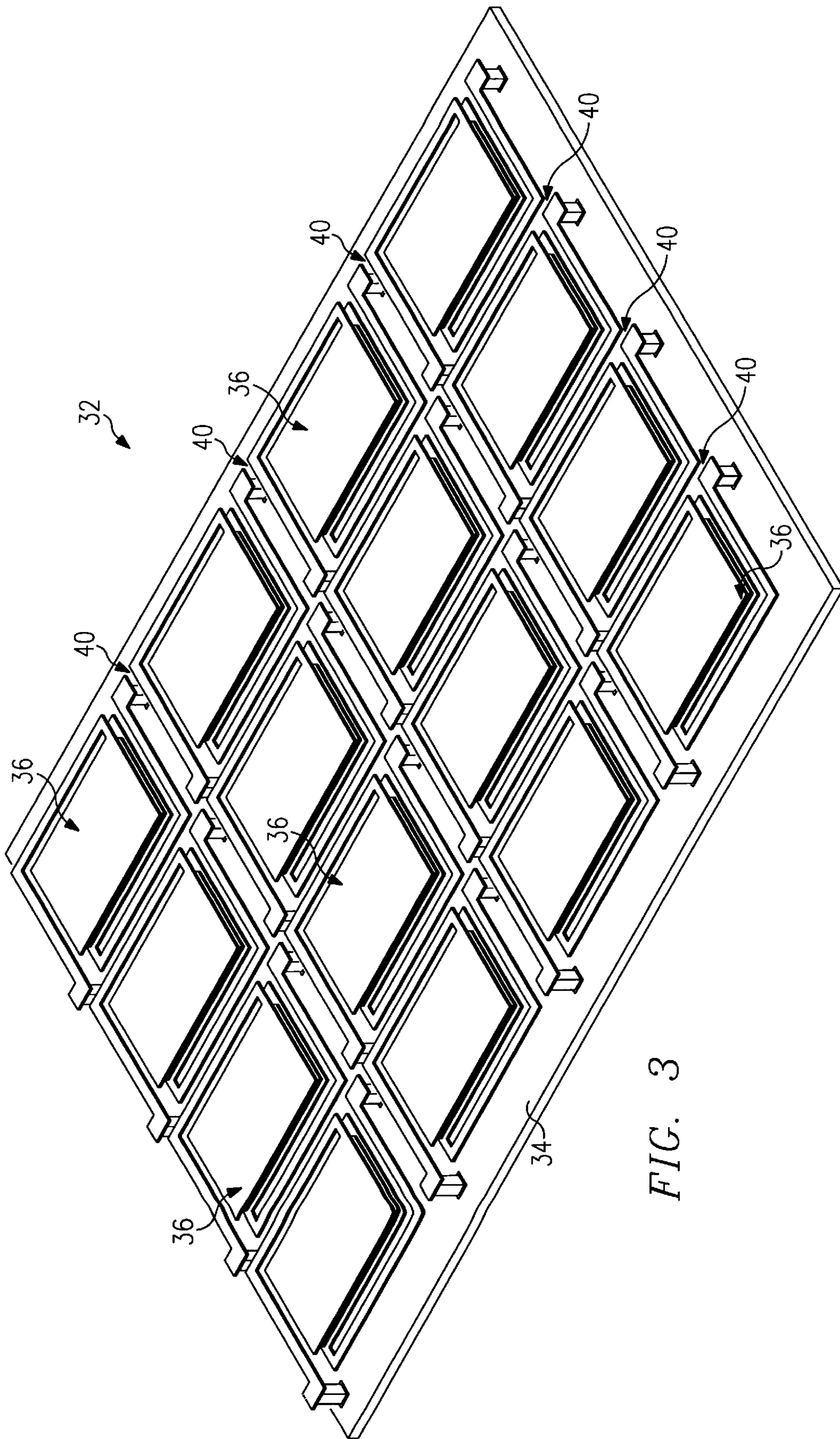


FIG. 3

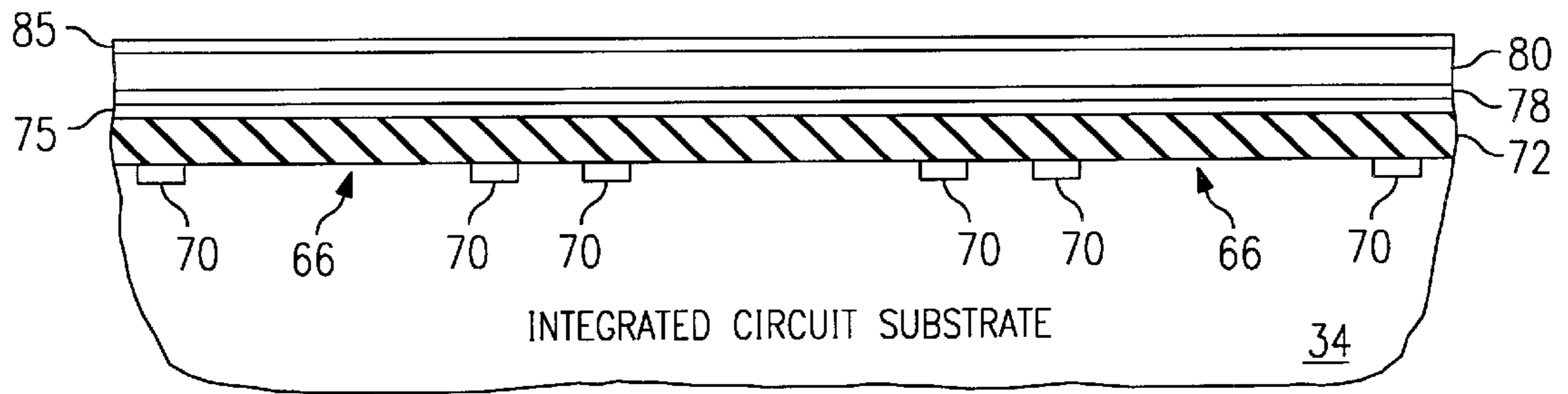


FIG. 5A

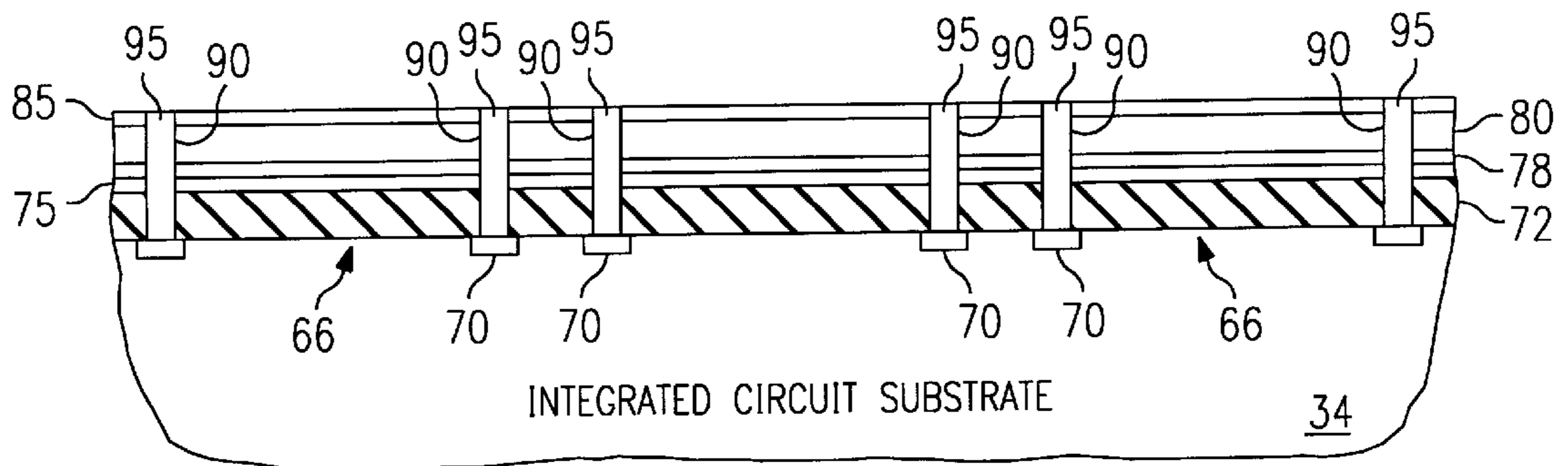


FIG. 5B

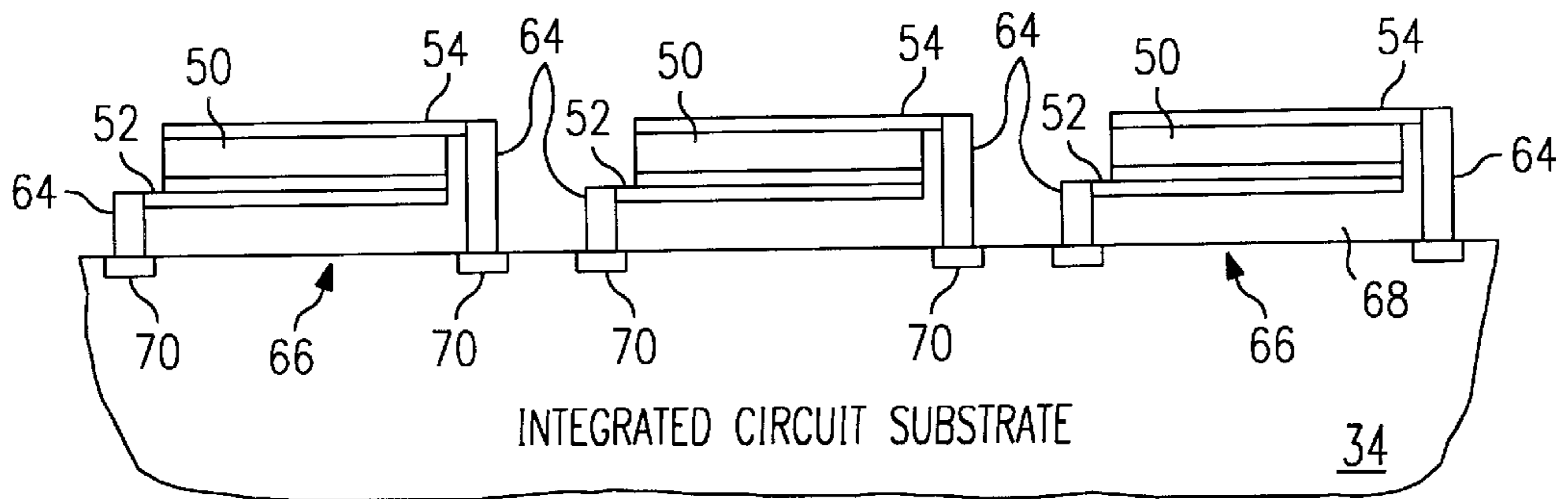


FIG. 5C

THERMAL DETECTOR WITH NUCLEATION ELEMENT AND METHOD

RELATED APPLICATIONS

This application claims priority under 35 USC § 119 (e)(1) of provisional application Ser. No. 60/024,912, filed Aug. 30, 1996.

This application is related to copending U.S. patent application Ser. No. 08/924,488, entitled "THIN FILM ELECTRODE AND METHOD"; copending U.S. patent application Ser. No. 08/919,821, entitled "THERMAL DETECTOR WITH PREFERENTIALLY-ORDERED THERMALLY SENSITIVE ELEMENT AND METHOD"; copending U.S. patent application Ser. No. 08/916,039, entitled "METAL ORGANIC DECOMPOSITION (MOD) METHOD OF FORMING THERMALLY SENSITIVE ELEMENT"; copending U.S. patent application Ser. No. 08/919,729, entitled "THERMAL DETECTOR WITH INTER-DIGITATED THIN FILM ELECTRODES AND METHOD"; copending U.S. patent application Ser. No. 08/920,261, entitled "THERMAL DETECTOR WITH STRESS-ALIGNED THERMALLY SENSITIVE ELEMENT AND METHOD"; copending U.S. patent application Ser. No. 910,687, entitled "METHOD OF PREFERENTIALLY-ORDERING A THERMALLY SENSITIVE ELEMENT".

TECHNICAL FIELD OF THE INVENTION

This invention relates generally to infrared or thermal imaging systems, and more particularly to a thermal detector with a nucleation element and to a method of fabrication.

BACKGROUND OF THE INVENTION

Thermal imaging systems are often employed to detect fires, overheating machinery, planes, vehicles and people, and to control temperature sensitive industrial processes. Thermal imaging systems generally operate by detecting the differences in thermal radiance of various objects in a scene and by displaying the differences as a visual image of the scene.

The basic components of a thermal imaging system generally include optics for collecting and focusing thermal radiation from a scene, a thermal detector having a plurality of thermal sensors for converting thermal radiation to an electrical signal, and electronics for amplifying and processing the electrical signal into a visual display or for storage in an appropriate medium. A chopper is often included in a thermal imaging system to A.C. couple the detector to the scene. The chopper produces a constant background radiance which provides a reference signal. The electronic processing portion of the thermal imaging system will subtract the reference signal from the total radiance signal to produce a signal with minimum background bias.

The thermal sensors of a thermal imaging system may be disposed in a focal plane array. The focal plane array and its associated thermal sensors are often coupled to an integrated circuit substrate with a corresponding array of contact pads and a thermal isolation structure disposed between the focal plane array and the integrated circuit substrate. The thermal sensors define the respective picture elements or pixels of the resulting thermal image.

One type of thermal sensor includes a thermally sensitive element formed from pyroelectric material which exhibits a state of electrical polarization and/or change in dielectric constant dependent upon temperature changes of the pyro-

electric material in response to incident infrared radiation. A pair of thin film electrodes are generally disposed on opposite sides of the pyroelectric material to act as capacitive plates. In this arrangement, the pyroelectric material acts as a dielectric, or insulator, disposed between the capacitive plates. Accordingly, the electrodes are operable to measure the charge generated by the pyroelectric material in response to changes in temperature. As previously discussed, the charge, or electrical signal, may be amplified and processed into a visual display.

The starting place for fabricating a thermal sensor is typically a wafer of silicon or other suitable material. The wafer may have a diameter of about 150 millimeters (6 inches) and an approximate thickness of 660 microns (26 mils). The materials that form the thermal sensors may be deposited on the wafer in layers and removed as necessary.

SUMMARY OF THE INVENTION

A problem with producing thermal sensors having a pyroelectric layer, however, is that the pyroelectric material tends to orient itself during deposition with the elongated, or polar, axis of its crystals parallel to the electrodes. This orientation reduces the pyroelectric properties of the layer, which degrades the electrical signal and thus the visual display of the thermal sensor.

Accordingly, a need has arisen in the art for a method of preferentially-ordering a thermally sensitive element. The present invention provides a thermal detector with a nucleation element that substantially eliminates or reduces the disadvantages and problems associated with prior thermal detectors.

In accordance with the present invention, a thermal sensor may be mounted to a substrate and provide an image representative of the amount of thermal radiation incident to the thermal sensor. The thermal sensor may include a first thin film electrode, a nucleation element, a thermally sensitive element and a second thin film electrode. The first thin film electrode may be disposed adjacent to the nucleation element. The thermally sensitive element may be in electrical communication with the first thin film electrode. The thermally sensitive element may comprise a plurality of preferentially-ordered crystals. The second thin film electrode may be in electrical communication with the thermally sensitive element opposite the nucleation element.

More specifically, crystals of the thermally sensitive element may be preferentially-ordered by the nucleation element during the fabrication process. In accordance with one embodiment of the present invention, the thermally sensitive element may be formed on a surface of the nucleation layer opposite the first thin film electrode.

In accordance with a particular embodiment of the present invention, the thermally sensitive element may comprise a pyroelectric material. The pyroelectric material may be lead lanthanum zirconate titanate (PLZT). The nucleation element may comprise an anisotropic material. The anisotropic material may be bismuth titanate.

Important technical advantages of the present invention include providing an improved thermal imaging system. In particular, a nucleation element is provided that increases pyroelectric properties of a thermally sensitive element, which improves the electrical signal of the thermal sensor. The improved electrical signal, in turn, improves the visual display obtained from the thermal sensors.

Other technical advantages will be readily apparent to one skilled in the art from the following figures, descriptions, and claims.

BRIEF DESCRIPTION OF THE DRAWINGS

For a more complete understanding of the present invention, and the advantages thereof, reference is now made to the following description taken in conjunction with the accompanying drawings, in which:

FIG. 1 is a block diagram showing the components of one embodiment of a thermal imaging system constructed in accordance with the present invention;

FIG. 2 is an isometric view of the thermal detector of FIG. 1, showing a focal plane array mounted to an integrated circuit substrate opposite a thermal element;

FIG. 3 is a detailed isometric view of the focal plane, array of FIG. 2, showing a matrix of thermal sensors;

FIG. 4 is a detailed isometric view of one of the thermal sensors of FIG. 3, showing a thermally sensitive element and a nucleation element disposed between a pair of thin film electrodes; and

FIGS. 5A-C are a series of elevation views in section showing various stages of fabrication of the thermal sensor of FIG. 4 in accordance with one embodiment of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

The preferred embodiments of the present invention and its advantages are best understood by referring now in more detail to FIGS. 1-5 of the drawings, in which like numerals refer to like parts throughout the several views. FIG. 1 shows a schematic block diagram of a thermal imaging system 12 constructed in accordance with the present invention. During operation, the thermal imaging system 12 detects, processes, and displays the heat image of a scene 14.

The thermal imaging system 12 may be especially useful when imaging by means of visual wavelengths is unavailable, such as in the dark or when vision is impaired by smoke, dust, or other particles. In such conditions, the thermal imaging system 12 may detect thermal radiation in the infrared window. The infrared window is a wavelength region in the infrared spectrum where there is good transmission of electromagnetic radiation through the atmosphere. Typically, infrared detectors sense infrared radiation in the spectral bands from 3 to 5 microns (having an energy of 0.4 to 0.25 eV) and from 8 to 14 microns (having an energy of 0.16 to 0.09 eV). The 3-5 micron spectral band is generally termed the "near infrared band" while the 8 to 14 micron spectral band is termed the "far infrared band." Infrared radiation between the near and far infrared bands cannot normally be detected due to atmospheric absorption of the same. The thermal imaging system 12, however, is also useful during the day and when vision by means of the visual wavelengths is available. For example, the thermal imaging system 12 may be used to detect fires, overheating machinery, planes, vehicles and people, and to control temperature sensitive industrial processes.

As shown in FIG. 1, the thermal imaging system 12 may comprise a lens assembly 16 in optical communication with a thermal detector 18. The lens assembly 16 focuses or directs thermal radiation emitted by the scene 14 onto the thermal detector 18. The lens assembly 16 may include one or more lenses made of material that transmits thermal radiation, such as germanium. The design of the lens assembly 16 may be varied depending on the particular use of the thermal imaging system 12. For example, the lens assembly 16 may have a constant or a variable F-number and/or may be a single field of view or a zoom lens.

The thermal detector 18 may be cooled or uncooled. A cooled thermal detector is operated at cryogenic temperatures such as at the temperature of liquid nitrogen, to obtain the desired sensitivity to variation in infrared radiation. In cases where an uncooled detector 18 is used, a chopper 20 is often disposed between the lens assembly 16 and the thermal detector 18. Preferably, the lens assembly 16, thermal detector 18 and chopper 20 are contained within an associated housing (not shown). The thermal detector 18 may also be contained within a vacuum environment or an environment of low thermal conductivity gas.

The chopper 20 may be controlled by a signal processor 22 to periodically interrupt transmission of the thermal image to the thermal detector 18. Various types of mechanical and/or electrical choppers 20 may be satisfactorily used with the present invention. For example, the chopper 20 may be a rotating disk with openings that periodically block and let pass infrared radiation.

The placement of the lens assembly 16 and the chopper 20 with respect to thermal detector 18 is accomplished using well known principles of optical design as applied to thermal imaging systems. As previously described, the lens assembly 16 focuses thermal radiation emitted by the scene 14 onto the thermal detector 18. The thermal detector 18 translates the incoming thermal radiation into corresponding electrical signals for processing.

The electrical signals of the thermal detector 18 may be passed to the signal processor 22, which assembles electrical signals into video signals for display. As previously described, the signal processor 22 may also synchronize operation of the chopper 20. This synchronization enables the signal processor 22 to subtractively process incoming thermal radiation to eliminate fixed background radiation. The output of the signal processor 22 is often a video signal that may be viewed, further processed, stored, or the like.

The video signal of the signal processor 22 may be viewed on a local monitor 24 or fed to a remote monitor 26 for display. The local monitor 24 may be an eye piece containing an electronic viewfinder, a cathode ray tube, or the like. Similarly, the remote monitor 26 may comprise an electronic display, a cathode ray tube, such as a television, or other type of device capable of displaying the video signal. The video signal may also be saved to a storage medium 28 for later recall. The storage medium 28 may be a compact disk, a hard disk drive, random access memory, or any other type of medium capable of storing electronic video signals for later recall. Monitors and storage mediums are well known in the art and therefore will not be further described herein.

Electrical power to operate the thermal imaging system 12 may be provided by a power supply 30. The power supply 30 provides electrical power directly to the chopper 20, the thermal detector 18, the signal processor 22, and to the local monitor 24. Electrical power may also be provided to the lens assembly 16, when, for example, a motor is employed to zoom the lens assembly 16.

FIG. 2 is a detailed view of the thermal detector 18. The thermal detector 18 may comprise a focal plane array 32 mounted to a substrate 34. In one embodiment, the focal plane array 32 may include a number of thermal sensors 36 arranged in a matrix. The quantity and location of the thermal sensors 36 depend upon the N by M configuration desired for the focal plane array 32.

The configuration of the focal plane array 32 generally varies for different types of thermal detectors 18. In a "staring" thermal detector, for example, the entire thermal image is focused onto a large focal plane array. By contrast,

a "scanning" thermal detector uses a mirror or similar means to sweep successive portions of the thermal image across a small focal plane array. Usually, although not necessary for the invention, both types of thermal detectors **18** consist of a number of thermal sensors **36**, with the output of each thermal sensor **36** representing a portion of the viewed scene **14**. For example, the output of each thermal sensor **36** in focal plane array **32** may represent a single pixel of the total image. This embodiment may be particularly beneficial for use in connection with high density visual displays.

The substrate **34** may be an integrated circuit substrate that provides the necessary electrical couplings and circuitry to process the thermal image formed on the focal plane array **32**. The integrated circuit substrate **34** may be formed of silicon, ceramic alumina, or other suitable materials which are both chemically and thermally compatible with the multiple layers which will be formed on the surface **66** (FIG. **4**) of the integrated surface substrate **34**. Further information regarding thermal sensors mounted on an underlying integrated circuit substrate is disclosed by U.S. Pat. No. 4,143,269 issued to McCormack, et al., entitled "Ferroelectric Imaging System" and U.S. Pat. No. 5,021,663 issued to Hornbeck, entitled "Infrared Detector."

A thermal element **38** may be provided to maintain the integrated circuit substrate **34** at a constant predefined temperature. The constant temperature prevents ambient or internally generated temperature gradients from affecting the thermal sensors **36** and thus provides a baseline with which the thermal energy of the scene **14** can be accurately measured. The necessary electrical couplings and circuitry to control the thermal element **38** may be provided by the integrated circuit substrate **34**. In such a case, the thermal element **38** may be coupled to the integrated circuit substrate **34** opposite the focal plane array **32**.

FIG. **3** illustrates a detailed view of the previously described focal plane array **32**. In this embodiment, the focal plane array **32** includes a matrix of thermal sensors **36**. Each thermal sensor **36** forms a discrete element of the focal plane array **32**. The thermal sensors **36** may be separated by a set of intersecting slots **40** provided around the perimeter of each thermal sensor **36**. The slots **40** provide a high degree of reticulation between adjacent thermal sensors **36** that substantially reduces thermal spreading between the pixel elements.

The thermal sensors **36** may detect thermal radiation using various techniques. For example, the thermal sensors may be based upon the generation of a charge due to a change in temperature resulting from thermal radiation heating the thermal sensors **36**. Alternatively, the thermal sensors **36** may be based upon the generation of a charge due to a photon-electron interaction within the material used to form the thermal sensors **36**. This latter effect is sometimes called the internal photoelectric effect. The thermal sensors **36** may also be based upon the change in resistance of a thin conductor caused by the heating effect of thermal radiation. Such thermal sensors **36** are sometimes referred to as bolometers. It will be understood that these and other types of thermal sensors **36** may be used in accordance with the present invention.

FIG. **4** illustrates a detailed view of one of the thermal sensors **36**. Each thermal sensor **36** may include a thermally sensitive element **50** disposed between a first electrically conductive element **52** and a second electrically conductive element **54**.

A significant feature of the present invention is the crystallographic orientation of the thermally sensitive ele-

ment **50**. Preferentially-ordered crystals are crystals arranged out of their natural orientation. Pyroelectric materials tend to have a natural orientation with the elongated, or polar, axis parallel to the electrodes. The preferentially-ordered crystals may be oriented within **45** degrees of normal to the electrodes. Preferably, the polar axis of the crystals is aligned normal to the electrically conductive elements **52** and **54**. This orientation increases pyroelectric properties of the thermally sensitive element **50** relative to the electrically conductive elements, which improves the electrical signal of the thermal sensor. The improved thermal sensor improves the visual display obtained from the thermal detector **18**.

As described in more detail below, crystals of the thermally sensitive element **50** may be preferentially-ordered during the fabrication process by a nucleation element **55**. The nucleation element **55** crystallizes before the thermally sensitive element **50** to provide a template from which crystals of the thermally sensitive element **50** may grow.

In one embodiment, the thermally sensitive element **50** is preferably formed from pyroelectric materials. The pyroelectric materials may also be ferroelectric materials such as barium strontium titanate (BST), barium titanate (BT), and antimony sulfoiodide (SbSI), or any lead containing ferroelectric material including lead titanate (PT), lead lanthanum titanate (PLT), lead zirconate titanate (PZT), lead lanthanum zirconate titanate (PLZT), lead zinc niobate (PZN), lead strontium titanate (PSrT), and lead scandium tantalate (PST). In this embodiment, the thermally sensitive element **50** generates a charge in response to a change in temperature. It will be understood, however, that the present invention contemplates forming the thermally sensitive element **50** from any thermal sensitive material that provides a satisfactory response to thermal radiation.

The thickness of the thermally sensitive element **50** may vary depending upon the wavelength of thermal radiation that the thermal imaging system **12** is designed to detect. The thermally sensitive element **50** is preferably a thin film to enhance responsiveness to thermal radiation and transmission of a generated charge to the electrically conductive elements **52** and **54**.

The first electrically conductive element **52** and the second electrically conductive element **54** may be disposed on opposite sides of the thermally sensitive, or pyroelectric, element **50**. In this arrangement, the electrically conductive elements **52** and **54** function as electrodes that receive charges generated by the pyroelectric element **50** in response to thermal radiation. Accordingly, the electrodes **52** and **54** are in electrical communication with the pyroelectric element **50**, which includes capacitive coupling.

The electrically conductive elements, or electrodes, **52** and **54** may be thin film electrodes. Thin film electrodes **52** and **54** are generally preferred because they may be virtually transparent to thermal radiation. Thin film electrodes are also preferred because they do not rob absorbed thermal energy from the pyroelectric element **50**. Additionally, the thin film electrode **52** may be opaque if the infrared radiation is absorbed in a chamber **68** of the thermal sensor **36**.

The electrodes **52** and **54** may be constructed of a solid solution of platinum and rhodium as described in related U.S. patent application Ser. No. 08/924,488, entitled "THIN FILM ELECTRODE AND METHOD." Alternately, the electrodes **52** and **54** may be formed of various single component materials that are electrically conductive. For example, the second electrode **54** may be formed of palladium or platinum, or from conductive oxides such as ruthenium oxide (RuO₂) or lanthanum strontium cobalt oxide (LSCO).

The nucleation element **55** is preferably disposed adjacent to the first electrode **52**. The nucleation element **55** may be disposed adjacent to the first electrode **52** opposite the thermally sensitive element **50** or between the first electrode **52** and the thermally sensitive element **50**. In an embodiment in which the nucleation element **55** is disposed between the first electrode **52** and the thermally sensitive element **50**, the nucleation element **55** may be in series with the thermally sensitive element **50**. Accordingly, if it is not desired to have the nucleation element **55** in series with the thermally sensitive element **50**, it may be preferred to dispose the nucleation element **55** adjacent the first electrode **52** opposite the thermally sensitive element **50**. In this embodiment, the nucleation element **55** may communicate a crystallographic orientation to the thermally sensitive element through the first electrode **52** during the fabrication process.

A barrier layer may be formed adjacent to the nucleation element **55**. A barrier layer may be desired, when, for example, the material of the nucleation element **55** is not compatible with the first electrode **52** or the thermally sensitive element **50**. In such a case, the nucleation element **55** may communicate a crystal orientation to the thermally sensitive element **50** through the barrier layer.

The thermal sensor **36** is preferably self-supported above the integrated circuit substrate **34**. As shown by FIG. 4, a first support arm **56** preferably extends from the first electrode **52**. A second support arm **58** preferably extends from the second electrode **54**. In another embodiment, the thermally sensitive element **50** may be divided into separate sections and the support arms **56** and **58** may extend from a bifurcated electrode **52** or **54**.

For many applications, the support arm **56** is preferably formed from the same type of material as the first electrode **52**. Similarly, the support arm **58** is preferably formed from the same type of material as the second electrode **54**. The support arms **56** and **58** however may be formed of a different material than the electrodes **52** and **54**. Additionally, the thickness of the support arms **56** and **58** may be varied to control thermal conductance between the electrodes and the integrated circuit substrate **34**. Thermally sensitive material may be disposed above the support arm **56** and below the support arm **58**.

The length, width and thickness of the support arms **56** and **58** may be selected to enhance their resistance to the transfer of thermal energy between the thermal sensor **36** and the integrated circuit substrate **34**. In one embodiment, for example, slots **60** and **62** may be formed between each support arm and its respective electrode to bifurcate the support arms and thus provide additional thermal isolation between the support arms and their associated electrodes. In this embodiment, the thermal isolation of each support arm may be increased by lengthening the bifurcated support arm. Thermal isolation may be maximized by fully extending each support arm along opposite halves of the perimeter of the electrodes.

A pair of posts **64** may be provided to support the bifurcated support arms **56** and **58**, and thus the thermal sensor **36**, in spaced relation with a surface **66** of the integrated circuit substrate **34**. The posts **64** may each support one of the bifurcated support arms. The posts **64** are preferably formed from material which is electrically conductive. In this embodiment, each post **64** may transmit electrical signals from its respective electrode to a contact pad **70** of the integrated circuit substrate **34**. Thus, the posts **64** provide both mechanical support and a signal flowpath to the associated contact pad **70**.

A chamber **68** may be formed by the gap between the bottom of the first electrode **52** and the surface **66** of the integrated circuit substrate **34**. The pyroelectric element **50** may absorb thermal radiation directly or in part after the radiation has passed through the chamber **68** and reflected off the integrated circuit substrate **34**. For an embodiment in which thermal radiation is absorbed in part after reflecting off the integrated circuit substrate **34**, the dimensions of the chamber **68** may be varied depending upon the wavelength of the thermal radiation that the thermal imaging system **12** is designed to detect. The chamber **68** preferably corresponds to about one-fourth of the selected thermal radiation wavelength. Thus, if thermal imaging system **12** is designed to detect thermal radiation having a wavelength of 7.5 to 14 microns, the chamber **68** preferably has a height of approximately two to three microns. In this embodiment, the electrodes **52** and **54** may be transparent to thermal radiation. The ability to vary the position of bottom of the first electrode **52** with respect to the surface **66** of the integrated substrate **34** enhances the responsiveness of thermal sensor **36** to thermal radiation.

FIGS. 5A–C depict various steps during the process of fabricating the thermal sensors **36** in accordance with an embodiment of the present invention. As shown in FIG. 5A, an array of contact pads **70** may be disposed on the surface **66** of the integrated circuit substrate **34** to receive electrical signals generated by the thermal sensors **36**. As previously described, the integrated circuit substrate **34** may be formed from silicon or other suitable materials which are both chemically and thermally compatible with the multiple layers which will be formed on the surface **66** of the integrated surface substrate **34**.

A sacrificial layer **72** may be deposited on the integrated circuit substrate **34**. During the fabrication process, the sacrificial layer **72** forms a base upon which the thermal sensors **36** may be formed in space relation with the integrated circuit substrate **34**. Accordingly, the sacrificial layer **72** may be removed after processing to yield the chamber **68**.

The sacrificial layer should have a thickness equal to the desired height of the chamber **68**. As previously described, the height of the chamber preferably corresponds to one-fourth of the selected thermal radiation wavelength. Thus, if thermal sensors **36** are to detect thermal radiation having a wavelength of 7.5 to 14 microns, the sacrificial layer should be deposited in a thickness of approximately two to three microns. The sacrificial layer **72** is preferably silicon dioxide (SiO_2) or polyimide or a similar type of material compatible with fabrication of the thermal sensors **36**. A material is compatible with the fabrication of the thermal sensors **36** when it will not inordinately shrink or expand or burn, melt or interact with other materials to an extent that it interferes with processing. The material of the sacrificial layer **72** is also preferably removable by way of dry etching techniques.

A first layer of electrically conductive material **75** or a nucleation layer **78** may next be formed on the sacrificial layer **72**. As described below, the first layer of electrically conductive material **75** will form the first electrode **52**. The first layer of electrically conductive material **75** may be formed of various types of materials such as palladium or platinum, or from conductive oxides such as ruthenium oxide (RuO_2) or lanthanum strontium cobalt oxide (LSCO). However, the present invention allows other types of electrically conductive material to be used depending on the type of thermal sensors **36** which will be formed on the integrated circuit substrate **34**. For example, as previously described, the first layer of electrically conductive material **75** may be constructed of a solid solution.

The nucleation layer **78** will form the nucleation element **55**. The nucleation layer **78** provides a template with which the crystallographic orientation of the thermally sensitive element **50** may be preferentially-ordered. Preferably, the nucleation layer **78** orders the polar axis of the crystals normal to the electrodes **52** and **54**. If not normal to the electrodes **52** and **54**, the polar axis of the crystals may be at an angle greater than ninety degrees. The normal orientation increases the pyroelectric coefficient of the layer relative to the electrodes and thus maximizes performance. Additionally, the dielectric constant may be minimized for tetragonal perovskite materials.

The nucleation layer **78** may be formed of various types of material. Preferably, the nucleation layer **78** comprises anisotropic material in that it has a strong driving force toward a particular orientation. Thus, the nucleation layer **78** provides a strong growth axis for aligning the thermally sensitive element **50**. The nucleation material may be bismuth titanate, yttrium barium copper oxide (YBCO), chrome, strontium barium niobate and the like.

A layer of thermally sensitive material **80** may next be formed on the nucleation layer **78** or the first layer of electrically conductive material. The layer of thermally sensitive material **80** will form the thermally sensitive element **50**. The layer of thermally sensitive material **80** may be formed in an amorphous state. The amorphous thermally sensitive layer **80** may be later crystallized in alignment with the nucleation layer **78**. Alternatively, the layer of thermally sensitive material **80** may be crystallized as it forms on the nucleation layer **78**.

In one embodiment, the layer of thermally sensitive material **80** is preferably formed from pyroelectric material such as barium strontium titanate (BST), barium titanate (BT), and antimony sulfiodide (SbSI). In other embodiments, lead containing ferroelectric materials including lead titanate (PT), lead lanthanum titanate (PLT), lead zirconate titanate (PZT), lead lanthanum zirconate titanate (PLZT), lead zinc niobate (PZN), lead strontium titanate (PSrT), and lead scandium tantalate (PST) may be used to form the thermally sensitive layer **80**. The selection of material for the thermally sensitive layer **80** depends upon the type of thermal sensor **36** which will be formed on the integrated circuit substrate **34**.

The nucleation layer **78** should be crystallized before the thermally sensitive layer **80** to provide the template for preferentially-ordering the thermally sensitive layer **80**. Where the nucleation layer **78** is formed prior to the first layer of electrically conductive material **75**, the nucleation layer **78** may communicate with the thermally sensitive element **50** through the first layer of electrically conductive material **75**. In this embodiment, the nucleation layer **78** should also be crystallized before the first layer of electrically conductive material **75**. In this way, the nucleation layer **78** will align the first layer of electrically conductive material **75**, which in turn will align the thermally sensitive element **50**.

The nucleation layer **78**, first layer of electrically conductive material **75** and the thermally sensitive layer **80** may be crystallized by heating the respective layers. In one embodiment, the nucleation layer **78**, first layer of electrically conductive material **75** and the thermally sensitive layer **80** may be successively heated by a radiant energy source provided above the thermally sensitive layer **78** opposite the nucleation layer **78**. Accordingly, crystals of the thermally sensitive layer **80** will be preferentially-ordered in accordance with the crystallographic orientation of the

nucleation layer **78**. Heat sinking may also be used to protect the integrated circuit substrate **34** from the heat associated with crystallizing the nucleation layer **78** and the thermally sensitive layer **80**.

A barrier layer (not shown) may be formed between the nucleation layer **78** and the thermally sensitive layer **80** or first layer of electrically conductive material **75**. A barrier layer may be desired, when, for example, the material of the nucleation layer **78** is not compatible with the electrically conductive or thermally sensitive material. In such a case, the nucleation layer **78** may communicate a crystal orientation to the thermally sensitive material through the barrier layer and/or first layer of electrically conductive material **75**.

A second layer of electrically conductive material **85** may be formed on the thermally sensitive layer **80** opposite the nucleation layer **78** or first layer of electrically conductive material **75**. The second layer of electrically conductive material **85** will form the second electrode **54**. The second layer of electrically conductive material **85** may be formed of a solid solution or various types of materials such as palladium or platinum, or from conductive oxides such as ruthenium oxide (RuO₂) or lanthanum strontium cobalt oxide (LSCO). However, the present invention allows other types of electrically conductive material to be used depending on the type of the thermal sensors **36** which will be formed on the integrated circuit substrate **34**.

Various techniques may be used to form thin film layers **72**, **75**, **78**, **80** and **85**. Often these techniques are divided into two groups—film growth by interaction of a vapor deposited species with an associated substrate and film formation by deposition without causing changes to the associated substrate. The first group of thin film growth techniques includes thermal oxidation and nitridation of single crystal silicon and polysilicon. The formation of silicides by direct reaction of a deposited metal and the substrate is also frequently included in this first group of thin film growth techniques.

The second group of thin film growth techniques may be further divided into three subclasses of deposition. The first subclass is often referred to as chemical vapor deposition (CVD) in which solid films are formed on a substrate by the chemical reaction of vapor phase chemicals which contain the desired constituents for the associated thin film layer. The second subclass is often referred to as physical vapor deposition (PVD) in which the desired thin film layer is physically dislodged from a source to form a vapor and transport it across a reduced pressure region to the substrate. The dislodged layer is then condensed to form the desired thin film layer. The third subclass typically involves coating the substrate with a liquid which is then dried to form the desired thin film layer. The formation of thin film layers by PVD includes such processes as sputtering, evaporation and molecular beam epitaxy. Spin coating is one of the most commonly used techniques for depositing liquids on a substrate to form a thin film layer.

Thin film layers may also be satisfactorily grown in accordance with the teachings of the present invention by using techniques such as dipping, vapor phase deposition by sputtering or MOCVD, and sol/gel or metal organic decomposition (MOD) by spin coating. Processes should be selected to establish the desired electrical and thermal characteristics for the resulting thermal sensors **36**. Additionally, depending upon the type of materials used to form layers **72**, **75**, **78**, **80** and **85**, one or more buffer layers or protective layers (not shown) may be disposed between surface **66** of integrated circuit substrate **34** and/or layers **72**, **75**, **78**, **80** and **85**.

The various techniques may be integrated to allow fabrication of the thermal sensors **36** on integrated circuit

substrate **34** using processes associated with the manufacture of very large scale integrated circuits. Material usage and overall process efficiency associated with fabricating a focal plane array **32** may be substantially improved. For example, thermally sensitive layer **80** is preferably formed with approximately the same thickness as desired for thermal sensitive elements **50**. Thus, the possibility of polishing damage associated with previous techniques used to form thermal sensitive elements from pyroelectric materials have been substantially reduced or eliminated.

As shown by FIG. **5B**, a pair of vias **90** may be formed for each thermal sensor **36**. The vias **90** are preferably formed using anisotropic etching or other photolithographic techniques. The post **64** may be formed by filling the vias **90** with a supporting material. For one application, the supporting material **95** may be platinum. However, other types of material may be used for the post **64** depending on the type of thermal sensors **36** that are to be fabricated, as well as the temperatures and processes involved in fabrication.

As shown by FIG. **5C**, after forming the desired layers of material **72**, **75**, **78**, **80** and **85** on the surface **66** of the integrated circuit substrate **34** and the posts **64** in the layers, individual thermal sensors **36** may be defined on the integrated circuit substrate **34**. As previously discussed, the sacrificial layer **72** is removed during processing to form the cavity **68**. Various photolithographic techniques including anisotropic etching processes may be used to define the desired thermal sensors **36**. Depending upon the type of materials used to form layers **75**, **78**, **80** and **85**, the anisotropic etching processes may include oxygen-based ion milling, reactive ion etch (RIE) or a magnetically enhanced reactive ion etch (MERIE).

In the resulting thermal sensors **36** the first electrode **52** is preferably formed from the first layer of electrically conductive material **75**. The nucleation element **55** is preferably formed from the nucleation layer **78**. The thermally sensitive element **50** is preferably formed from the thermally sensitive layer **80**. The second electrode **54** is preferably formed from the second layer of electrically conductive material **85**. The posts **64** are formed from the supporting material **95** in the vias **90**. In one embodiment, the post **64** for the bottom electrode **52** may extend past the bottom electrode to the height of the post **64** of the top electrode. The posts **64** rest on the contact pads **70**.

Additionally, the thermal sensors **36** preferably include the cavity **68** between the first electrode **52** and the surface **66** of integrated circuit substrate **34**. As previously discussed, the cavity **68** will preferably have a height which corresponds to about one quarter of the wavelength of the incident infrared radiation which will be detected by thermal sensors **36**. For one application, post **64** and the associated cavity **68** have a height of approximately two and one-half microns.

The sole table below provides an overview of some embodiments in the drawings.

Drawing Element	Preferred or Specific Term	Generic Term	Alternate Terms
16	Lens Assembly	Optics	
20	Chopper	Device that interrupts beam of radiation	
22	Signal Processor	Electronics	
24	Monitor	Display	Electronic viewfinder, Cathode ray tube

-continued

Drawing Element	Preferred or Specific Term	Generic Term	Alternate Terms
32	Focal plane array	Matrix of thermal sensors	
34	Integrated circuit substrate	Silicon switching matrix	
36	Pyroelectric sensors	Thermal sensors	Bolometers
50	Pyroelectric element	Thermally sensitive element	Barium strontium titanate (BST), barium titanate (BT), and antimony sulfiodide (SbSI), or any lead containing ferroelectric material including lead titanate (PT), lead lanthanum titanate (PLT), lead zirconate titanate (PZT), lead lanthanum zirconate titanate (PLZT), lead zinc niobate (PZN), lead strontium titanate (PSrT), and lead scandium tantalate (PST). Solid solution, platinum or palladium
52	First thin film electrode	First electrically conductive element	Solid solution, platinum or palladium
54	Second thin film electrode	Second electrically conductive element	Solid solution, platinum or palladium
55	Nucleation element	Template	Anisotropic material
64	Post	Mechanical support	

Although the present invention has been described with several embodiments, various changes and modifications may be suggested to one skilled in the art. Thus, it is intended that the present invention encompass such changes and modifications as fall within the scope of the appended claims.

What is claimed is:

1. A thermal sensor mounted to a substrate to provide an image representative of the amount of thermal radiation incident to the thermal sensor, comprising:
 - a nucleation element;
 - a first thin film electrode disposed adjacent to the nucleation element;
 - a thermally sensitive element comprising a plurality of preferentially ordered crystals, the preferential ordering of said crystals resulting from the presence of said nucleation element, said thermally sensitive element being in electrical communication with the first thin film electrode; and
 - a second thin film electrode in electrical communication with the thermally sensitive element.
2. The thermal sensor of claim 1, wherein the first thin film electrode is disposed adjacent to the thermally sensitive element opposite the second thin film electrode.
3. The thermal sensor of claim 1, the preferentially-ordered crystals each further comprising a polar axis normal to the electrodes.
4. The thermal sensor of claim 1, wherein the thermally sensitive element is a pyroelectric material.

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5. The thermal sensor of claim 1, wherein the thermally sensitive element comprises lead lanthanum zirconate titanate (PLZT).

6. The thermal sensor of claim 1, wherein the nucleation element comprises bismuth titanate.

7. A thermal sensor mounted to a substrate to provide an image representative of the amount of thermal radiation incident to the thermal sensor, comprising:

a nucleation element;

a first thin film electrode disposed adjacent to the nucleation element;

a thermally sensitive element comprising a plurality of preferentially ordered crystals in electrical communication with the first thin film electrode; and

a second thin film electrode in electrical communication with the thermally sensitive element;

the nucleation element being disposed adjacent to the thermally sensitive element opposite the second thin film electrode.

8. A thermal sensor mounted to a substrate to provide an image representative of the amount of thermal radiation incident to the thermal sensor, comprising:

a nucleation element;

a first thin film electrode disposed adjacent to the nucleation element;

a thermally sensitive element comprising a plurality of preferentially ordered crystals in electrical communication with the first thin film electrode; and

a second thin film electrode in electrical communication with the thermally sensitive element;

the thermal sensor of claim 1, further comprising a supporting structure to support the first thin film electrode in spaced relation with a surface of the substrate, the supporting structure comprising:

at least two posts extending from the surface of the substrate; and

a pair of bifurcated arms each extending from an electrode and connected to the respective posts.

9. A thermal imaging system for producing an image of a scene in response to incident thermal radiation from the scene, comprising:

optics for focusing incident thermal radiation emitted by the scene onto a focal plane array;

a chopper disposed between the optics and the focal plane array;

the focal plane array including a plurality of thermal sensors for detecting the incident thermal radiation mounted to a substrate with each thermal sensor comprising:

a nucleation element;

a first thin film electrode disposed adjacent to the nucleation element;

a thermally sensitive element comprising a plurality of preferentially ordered crystals, the preferential ordering of said crystals resulting from the presence of said nucleation element, said thermally sensitive element being in electrical communication with the first thin film electrode;

a second thin film electrode in electrical communication with the thermally sensitive element; and

electronics for receiving and processing the signal to obtain a video signal representing radiance differences emitted by objects in the scene.

10. The thermal imaging system of claim 9, the preferentially-ordered crystals each further comprising a polar axis normal to the electrodes.

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11. The thermal imaging system of claim 9, wherein the thermally sensitive element is a pyroelectric material.

12. The thermal imaging system of claim 9, wherein the thermally sensitive element comprises lead lanthanum zirconate titanate (PLZT).

13. The thermal sensor of claim 9, wherein the nucleation element comprises bismuth titanate.

14. A method for fabricating a thermal sensor comprising the steps of:

forming a first thin film electrode;

forming a nucleation element disposed adjacent to the first thin film electrode;

forming a thermally sensitive element comprising a plurality of preferentially ordered crystals, the preferential ordering of said crystals resulting from the presence of said nucleation element with said thermally sensitive element being in electrical communication with the first thin film electrode; and

forming a second thin film electrode in electrical communication with the thermally sensitive element.

15. A method for fabricating a thermal detector having a focal plane array of thermal sensors mounted to an integrated circuit substrate comprising the steps of:

forming a sacrificial layer of material on a surface of the integrated circuit substrate;

forming a thin film layer of thermally sensitive material layer;

forming a first thin film layer of electrically conductive material in electrical communication with the thermally sensitive layer;

forming a nucleation layer in communication with a surface of the thermally sensitive layer;

crystallizing the thin film layer of thermally sensitive material beginning at the surface in communication with nucleation layer;

forming a second thin film layer of electrically conductive material in electrical communication with the thermally sensitive layer opposite the first thin film layer; and

forming from the thin film layers of material a number of thermal sensors which form the focal plane array mounted to the integrated circuit substrate.

16. The method of claim 15, further comprising the steps of removing the sacrificial layer to form a cavity between the integrated circuit substrate and each thermal sensor.

17. The method of claim 15, wherein the thin film layer of thermally sensitive material crystallizes as it forms.

18. The method of claim 15, wherein the thin film layer of thermally sensitive material is formed on a surface of the nucleation layer opposite the first thin film layer.

19. The method of claim 15, wherein the step of crystallizing the thin film layer of thermally sensitive material beginning at the nucleation layer comprises the step of heating the thermally sensitive material to preferentially-order crystals of the thermally sensitive material.

20. The method of claim 19, wherein the preferentially-ordered crystals each include a polar axis normal to the thin film layers of electrically conductive material.

21. The method of claim 15, wherein the nucleation layer comprises an anisotropic material.

22. The method of claim 15, wherein the nucleation layer comprises bismuth titanate.

23. The method of claim 15, wherein the sacrificial layer is removed prior to crystallizing the thermally sensitive material.

UNITED STATES PATENT AND TRADEMARK OFFICE
CERTIFICATE OF CORRECTION

PATENT NO. : 5,945,673

DATED : August 31, 1999

INVENTOR(S) : Howard R. Beratan, et. al.

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

Column 13, line 29, after "electrode;" delete "and".

Column 13, line 31, after "element;" insert --and--.

Column 13, line 32, delete "the thermal sensor of claim 1, further comprising".

Signed and Sealed this

Twenty-fourth Day of October, 2000

Attest:



Q. TODD DICKINSON

Attesting Officer

Director of Patents and Trademarks